A MULTI-SPARK PREIONIZATION SOURCE FOR DIFFUSE DISCHARGES CONTAINING ATTACHERS*

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Abstract

Diffuse discharge opening switches usually operate with gas mixtures containing attachers when short opening times are desired. For arc free discharge initiation, a preionization source should produce a sufficient electron density at the time when the voltage rises across the discharge. Therefore, a preionizer must have 1) a short rise and fall time, 2) sufficient power, and 3) a sufficiently precise timing system to synchronize preionization and main discharge.

A device to generally fulfill these requirements is described. The energy for the preionization source is stored in eight individual coax cables and switched with one master gap into eight cables that are terminated by individual multi-spark gaps arrays. The gap for the main discharge and the master gap for the preionizer are triggered by a single laser using a beam splitter. The optical delay of the light pulse controls the synchronization. Experiments showing delay, preionization pulse length, and jitter are presented.

Introduction

Externally controlled diffuse discharges have been considered to be promising candidates for the realization of fast rep-rated opening switches [1,2]. Opening means a decrease in the switch conductivity and is in general only determined by a decrease in the electron density. Since recombination at electron densities of $n_e \sim 10^{14}$ cm^{-3} is too slow, attacher can be used [2]. To avoid high losses in the switch the attacher should not be effective to any substantial degree in the conduction phase. One possibility would be to use attachment as a control mechanism e.g. optically induced attachment or photodetachment [2,3]. For all other control mechanisms however the attacher should exhibit the following conditions [1].

(a) low attachment rate coefficient k_{attach} at low values of E/N.
(b) high attachment rate coefficient k_{attach} at high values of E/N.

These requirements do not necessarily mean that the derivative $d(k_{attach})/d\,(E/N)$ is positive under steady state operating conditions of a discharge. This situation has been known to cause instabilities [4]. However, any switching process and the initiation of the discharge itself will always cause a transition through such an unstable state. Therefore any gas discharge device used for this opening application has to permit very fast transitions through this state to avoid arcing [5]. For a self sustained discharge therefore the preionization has to be optimized with respect to several parameters:

(1) preionization power
(2) preionization pulse length
(3) preionization rise and fall times
(4) preionization timing with respect to the applied discharge voltage
(5) proper illumination of the gap

This paper describes a UV preionizer capable of achieving the objectives aforementioned.

Requirements

The investigation and optimization of an efficient UV preionization system for gases containing attachers, requires one to consider the following processes and their time constants.

(1) Photoionization
In UV preionization, the dominant process will be one step photoionization and as such the electron generation rate will, to a first approximation, be proportional to the preionization intensity.

(2) Attachment
In attaching gases, electron depletion is dominated by attachment, thus for a constant electron generation rate the steady state electron density will depend solely on the attachment rate. For an attaching species with an attachment rate coefficient dependent on E/N as mentioned previously, the rate will be low before the voltage is applied, rise drastically when the voltage reaches its maximum value, and decrease again when the voltage drops as the conductivity increases.

(3) Collisional Detachment
It has been pointed out by several researchers that negative ions may serve as a reservoir of electrons for the initiation of diffuse discharges, since cross sections for collisional detachment have, in general, much lower threshold levels than those for ionization. This may only be effective if the negative ion density reaches a value nearly the same order of magnitude as the electron density in the steady state discharge.

(4) Recombination
Ion-ion recombination has relatively large cross sections. During the period of preionization in gases containing attaching species the negative and positive ion density will increase and thus the negative ion lifetime will decrease and limit the negative ion density.

The effect of the above processes on the efficiency of the preionization system is demonstrated in Fig. 1. During a short preionization pulse (short compared to the time constant of attachment) the electron density rises nearly linearly with time while the negative ion density remain small compared to the electron density. After the preionization pulse, the electron

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14. ABSTRACT
Diffuse discharge opening switches usually operate with gas mixtures containing attachers when short opening times are desired. For arc free discharge 1nitiation, a preionization source should produce a sufficient electron density at the time when the voltage rises across the discharge. Therefore, a preionizer must have 1) a short rise and fall time, 2) sufficient power, and 3) a sufficiently precise timing system to synchronize preionization and main discharge. A device to generally fulfill these requirements is described. The energy for the preionization source is stored in eight individual coax cables and switched with one master gap into eight cables that are terminated by individual multi-spark gaps arrays. The gap for the main discharge and the master gap for the preionizer are triggered by a single laser using a beam splitter. The optical delay of the light pulse controls the synchronization. Experiments showing delay, preionization pulse length, and jitter are presented.

15. SUBJECT TERMS

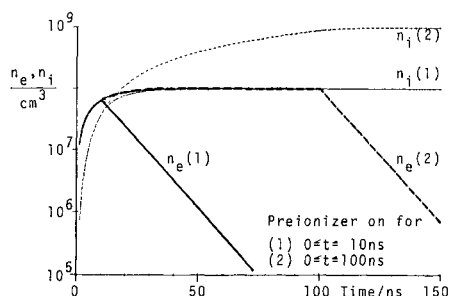| 16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **SAR**	18. NUMBER OF PAGES **3**	19a. NAME OF RESPONSIBLE PERSON
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Fig. 1 Time dependent electron - and negative ion density, calculated for:

$$R_{prei.} = 10^4 \text{ cm}^{-3} \text{ s}^{-1}$$

$$N_{attach} k_{attach} = 10^8 \text{ s}^{-1}$$

$$k_{ion \; rec.} = 10^6 \text{ cm}^3 \text{ s}^{-1}$$

for two different preionization pulse length

density decrease while the negative ion density increases as long as attachment is significant.

For a long preionization pulse (long compared to the time constant for attachment) the electron density reaches a steady state value while the negative ion density increases still further. The maximum electron density will depend linearly on the power of the preionizer. Depending upon the value of the cross section for ion-ion recombination, the ion density may also reach a steady state value.

From these general considerations it becomes obvious that a preionization only be used efficiently for a time T_1 (if only electron generation is considered) or for a time T_2 if in addition the production of a reservoir of negative ions is thought to be beneficial. In general it is expected that the electron density is of principal import and, therefore the preionization pulse should not terminate before the voltage is applied across the discharge region.

The optimum preionization time (T_1 or T_2) depend strongly on the attaching species used and its concentration. A preionization system should therefore allow for adjustment of the following parameters

(1) preionization power
(2) preionization pulse length
(3) rise and fall time to allow for the generation of short pulses
(4) precise adjustable timing with respect to the main discharge
(5) uniform preionization of the discharge volume

Design and Construction

It was decided to use a multi spark UV preionization source [6] since UV rich sparks are fairly easy to produce and gas degradation is of minor importance in these low rep rate systems with moderate gas exchange requirements. Coaxial cables were chosen as energy storage elements to drive the spark sources, thus allowing the device to produce rectangular pulses with fast rise and fall times. Eight multi-spark sources were connected to eight coaxial transmission lines. Eight similiar lines act as charging lines and were switched by an impedance matched master spark gap (Fig. 2).
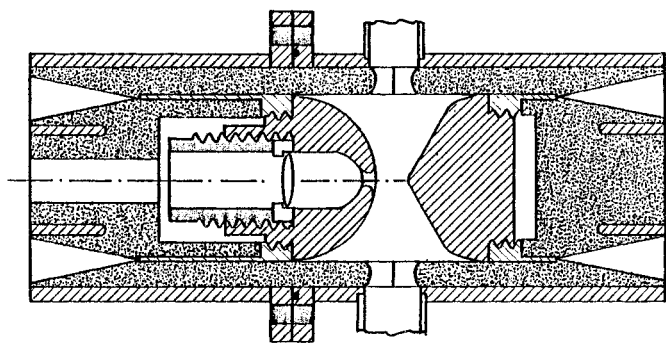

Fig. 2 Preionization Spark Gap Design

The switch design allows one to change the charging lines and thus vary the pulse length of the preionization pulse. The cables used had an impedance of 75 Ω and were rated at 80 kV dc (Belden 8870). This made the total system impedance 9.3 Ω, with a capacitance of 240 pF per meter of charging line for eight cables. The energy stored·was 0.05 Joules per meter at 20 kV or 0.8 Joules per meter at 80 kV. Both spark gaps, i.e. the gap used to switch the main discharge and the master gap for the preionizer, are laser-triggered gaps [7]. One laser and a beam splitter was used, and the delay between preionization and discharge initiation adjusted by changing the optical path length for the beam that triggers the main discharge.

The design of the two laser triggered gaps is in principle the same. The design of the master gap for the preionization source is shown in Fig. 2. The laser beam is entrant into the gap axially through an aperture in one electrode. The other electrode in each gap is conical with a rounded tip. This shape ensures that the laser strikes the highest field point, and that laser triggered breakdown starts in the same region on the conical electrode where self breakdown occurs. This shape ensures that the gap can be laser triggered with minimum jitter in a voltage region close to self breakdown.

The eight individual spark sources at the ends of the eight transmission lines allow for location of the preionization sources in the discharge chamber at different position. For our experiments we intend to investigate preionization through a screen electrode as well as using a side-on configuration. In the present device the discharge is cylindrical and the spark sources are arranged in a radially symmetric pattern to meet the requirement for a uniform illumination of the discharge region. The individual multi spark sources were designed as shown in Fig. 3.
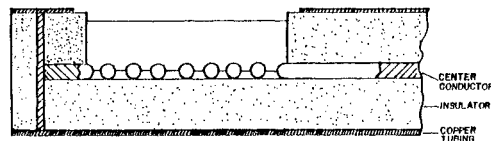

Fig. 3 UV Preionzier Design

The coaxial geometry is maintained as closely as possible. Eight sparks are distributed over a length of approximately 2 cm by using ball bearings as intermediate electrodes between the first and the last electrode. The individual gaps are highly overvolted so that they add little jitter to the system.

Results

In the first series of test experiments the light emitted from the multi spark sources, when operated in air, was monitored with a vacuum photodiode (Hamamatsu #R1328U) shown schematically in Fig. 4. The upper trace indicates the time dependent
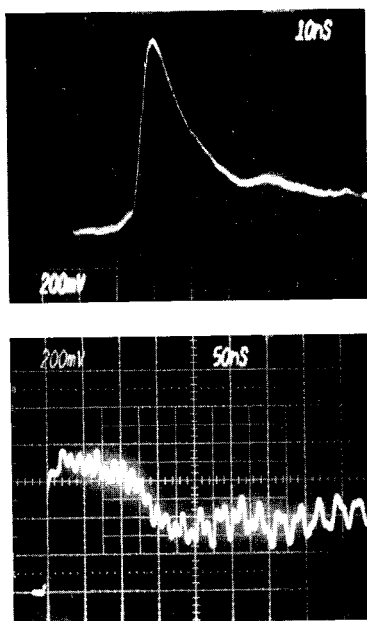

Fig. 4 Light Emission from UV Preionizer,
Charging cable length 2 m (top), 10 m (bottom)

light emission for a charging line length of 2m while the lower trace is for a line length of 10m. The charging voltage in both cases was 20 kV. The light pulse has a risetime of less than 5 ns and the pulse length clearly is adjusted by using different length for the charging cables. The rise time was found to be relatively independent of the charging voltage as long as the spark arrays were overvolted by at least 10% however with the longer cables the effect of the reflected electrical waves became much more pronounced. It should be pointed out that illuminating the photodiode with all eight multi-spark sources simultaneously did not change the monitored pulse shape or length. If a fast falltime is desired, it is necessary to accurately terminate the cables.

In a second set of experiments the timing characteristics of the system were tested. Both preionization and main line gaps were laser triggered, the main line being terminated with a matching resistor. The light from the preionization source and the voltage across the matching resistor were monitored using the same oscilloscope (see Fig. 5). Here the optical delay length between the two laser pulses was 13.5 m and charging line length of the preionizer was 2 mm (see Fig. 4), thus the delay between preionization and main system firing is ~ 45 ns. Fig. 5 presents the traces of four consecutive events showing that the jitter in this case was of

the order of 1 ns or less. The oscilloscope was triggered by a current probe in the preionizer transmission line, showing the optimum timing of this system. It should be pointed out, however, that we used very high power laser pulses (Ruby laser, pulse energy = 0.1 J per gap, pulse length = 50 ns). Although the laser pulse was focused at a point

VOLTAGE ACROSS TERMINATING RESISTOR

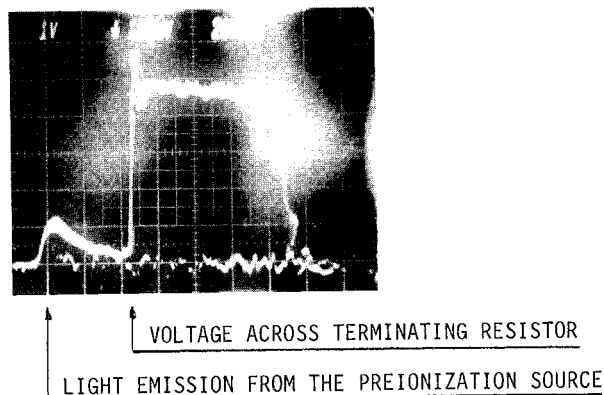LIGHT EMISSION FROM THE PREIONIZATION SOURCE

Fig. 5 UV Preionizer Timing (4 shots)

1-2 mm in front of the surface the opposite electrode, the laser tended to drill holes into the electrode surface. After several hundred shots without moving the focus on the electrode surface, the jitter increased markedly up to approximately 10-20 ns.

At the present time diffuse discharge experiments are being performed at atmosphere pressure in gas mixtures containing attaching species.

Acknowledgments

References

[1] Proc. ARO Workshop on Repetitive Opening Switches, Tamarron, CO (1981).

[2] Proc. ARO Workshop on Diffuse Discharge Opening Switches, Tamarron, CO (1982).

[3] K. H. Schoenbach, G. Schaefer, M. Kristiansen, L.L. Hatfield, and A.H. Guenther, "Concepts for Optical Control of Diffuse Discharge Opening Switches, IEEE Trans. on Plasma Sci. vol. PS-10, 246, 1982.

[4] D.H. Douglas-Hamilton and S.A. Mani, "Attachment Instability in a Externally Ionized Discharge", J. Appl. Phys., vol. 45, 4406, Oct. 1974.

[5] G. Schaefer, K.H. Schoenbach, P. Tran, and J.-S. Wang, "Computer Calculations of the Time Dependent Behavior of Diffuse Discharge Switches", Proceedings of the 3rd IEEE Pulsed Power Conference, Albuquerque, NM, June 1983.

[6] H. Sequin and J. Tulip, "Photoinitiated and photosustained laser," Appl. Phys. Lett., vol. 21, 414-415, 1972.

[7] A.H. Guenther and J.R. Bettis, "The laser triggering of high voltage switches", J. Phys. D: Appl. Phys., vol. 11, 1577-1613, 1978.

[8] C.L.M. Ireland, "A Multichannel Laser Triggered Spark Gap with Subnanosecond Risetime for Electro-optic Switching", J. Phys. E: Sci. Instr. vol. 8, 1007.